

Superfast Thinning of a Nanoscale Thin Liquid Film

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Abstract

This fluid dynamics video demonstrates an experiment on superfast thinning of a freestanding thin aqueous film. The production of such films is of fundamental interest for interfacial sciences and the applications in nanoscience. The stable phase of the film is of the order $5 - 50\text{ nm}$; nevertheless thermal convection can be established which changes qualitatively the thinning behavior from linear to exponentially fast. The film is thermally driven on one spot by a very cold needle, establishing two convection rolls at a Rayleigh number of 10^7 . This in turn enforces thermal and mechanical fluctuations which change the thinning behavior in a peculiar way, as shown in the video.

Thin liquid films may show a very thin stable phase of nanometer scale. Since the film is no longer visible by optical wavelengths at this thickness, it is called a Black Film [2]. The evolution of an initially thick, freestanding film towards this equilibrium thickness is a slow process which can be observed as a flat boundary of Black Film on top of a periodic color pattern moving downwards. The colors correspond to the repeated negative interference of light waves when the condition $n \cdot \lambda/4$ is met. This process is driven by gravitation and surface forces, but the time scale is set by the Poiseuille flow between the film interfaces [1], cf. Fig. 1, 75s and 115s.

When the thin film is driven, the motion may change due to the altered transport properties. We explore this possibility by thermal driving with a cold copper rod at 100 K , corresponding to a Rayleigh number of 10^7 . This establishes two stable convection rolls, Fig. 1, 195s–275s and gives

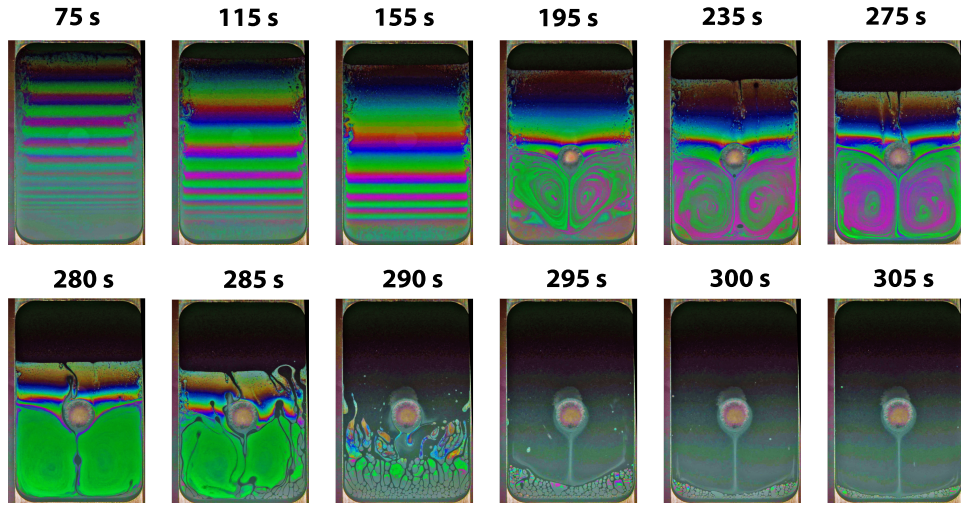


Figure 1: Thinning by turbulent convection. We show the film evolution for some dynamically interesting instants of time. While the usual thinning evolves slowly, convection mixes and transports material around very quickly until the regime of bubble convection is reached. The involved processes contain convection, turbulent mixing, surface forces, disjoining pressure and gravitation. The black area on the top of each picture contains optically invisible material of thickness $< 50 \text{ nm}$. The colors correspond to different thicknesses, corresponding to a negative interference of wavelength $n \cdot \lambda/4 = d$, i.e. a certain color can occur for several thicknesses. The time step in the first row is 40 s and 5 s in the second row.

rise to large mechanical and thermal fluctuations. These fluctuations in turn generate spontaneously spots of stable and light black film inside the unstable thick and heavy phase. The spots are convected for small size until they eventually escape to the top due to buoyancy. While being convected, the spots grow and leave behind tails of Black Film, thereby increasing the Black Film area in an exponential manner, cf. Fig. 1, 280 s – 305 s .

References

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